Indicator: Changing Stream Flows (029)

Flow is a critical aspect of the physical structure of stream ecosystems (Poff and Allan, 1995; Robinson et al., 2002). Low flows define the smallest area available to stream biota during the year. Even though riparian vegetation and aquatic life in ephemeral streams in arid and semi-arid regions have evolved to complete their life histories during periods when water is available, extended periods of no-flow can significantly impact their survival (Fisher, 1995). High flows shape the stream channel and clear silt and debris from the stream, and some fish species depend on high flows for spawning. The timing of high and low flows also influences many ecological processes. Changes in flow can be caused by dams, water withdrawals, groundwater pumping (which can alter baseflow), and changes in land cover (e.g., deforestation or urbanization) or climate (Calow and Petts, 1992).

This indicator, which combines two indicators reported on by The Heinz Center (2002), reports on trends in two aspects of stream flow in the lower 48 states:

- **Flow magnitude and timing:** The percentage of streams or rivers with major changes in the magnitude or timing of their average annual 1-day high flows or 7-day low flows in the decades, 1970s, 1980s, and 1990s, compared to a reference period from 1930 to 1949. This indicator is based on 867 stream gauging sites with at least 20 years of discharge records within the target dates 1930 to 1949, and all 30 years of records for the 1970s, 1980s, and 1990s.

- **No-flow periods**: The percentage of streams in primarily grassland and shrubland watersheds in which no-flow periods occurred during the 1950s, 1960s, 1970s, 1980s, and 1990s; and the percentage of these streams in which the duration of no-flow periods during each of these decades represents an increase or decrease of more than 50% compared to the 50-year average (1950-1999). This indicator is based on 408 gauging sites in primarily grassland/shrubland watersheds in the contiguous 48 states, but the second component (duration of no-flow periods) only considers a subset of 143 sites that had at least one no-flow day between 1950 and 1999.

What the Data Show

More than half of the streams and rivers showed changes of 75% or more in their high or low flows or a shift of 60 days or more in the timing of their high or low flows, compared to the period 1930-1949 (Figure 029-1). This percentage increased from 55% in the 1970s to 61% in the 1990s. The corresponding statistics for streams and rivers showing changes of 25-75% in their high or low flows or a shift of 30-60 days in the timing of their high or low flows are 35% and 30% in the 1970s and 1990s, respectively. Only 10% of the streams and rivers had alterations of flow of less than 25% or timing of fewer than 30 days, compared to the 1930-1949 period (http://www.heinzctr.org/ecosystems/fr_water/strm_flows.shtml).

Approximately one-third of the streams and rivers showed increases, decreases, and/or changes in timing of their average annual 7-day low flows, compared to the 1930-1949 period, with a slight increase in those exhibiting higher low flows (37% in the 1990s compared to 31% in the 1970s) (Figure 029-2). The percentage of streams with increases in high flow also increased, from 12% in the 1970s and 1980s to 31% in the 1990s. There was no discernable trend in decreasing high or low flows over the same time period. Figure 029-2 shows a slight upward trend in the percentage of streams and rivers showing changes in the timing of high flows, from 41% in the 1970s to 47% in the 1980s and 1990s. A similar trend is evident in the timing of low flows: 32% of streams showed significant changes in timing during the 1990s, up from 27% in the 1970s.

Overall, the percentage of streams and rivers experiencing periods of no flow decreased from 24% in the 1950s to 14% in the 1990s across grassland and shrubland regions of the United States (Figure 029-3).

Among streams experiencing periods of no flow, the duration of these periods also decreased between the 1950s and 1990s (Figure 029-4). In the 1950s, 38% of these streams and rivers experienced no-flow periods that were at least 50% longer than their long-term average (1950-1999). By the 1990s, only 10% of streams fell into this category. The percentage of streams with no-flow periods at least 50% shorter than their long-term average increased from 23% in the 1950s to 63% in the 1990s.

Taken together, these indicators point to increases in high and low flows in streams and rivers between the 1950s and the 1990s, with streams and rivers in grassland and shrubland regions experiencing fewer or shorter no-flow periods. The 1980s were a relatively wet period, featuring some of the smallest percentages of no-flow periods during the 50-year period of record.

Indicator Limitations

- The "magnitude and timing" component of this indicator compares stream flows in the decades from 1970 to 1999 with a baseline period, 1930-1949. Many dams and other waterworks had already been constructed by 1930, and this baseline period was characterized by low rainfall in some parts of the country. However, a similar analysis based on data from 506 watersheds (Forest Service, 2004) showed a tendency toward higher high- and low-flow rates in the decades of the 1940s, 1950's and 1960s compared to the earlier period 1879-1929.

- The "dry periods" component of this indicator compares stream flows in the decades from 1950 to 1999 with average stream flow over the full 50-year period. Like the baseline discussed above, this long-term average does not represent the "natural state" of stream flow because it postdates anthropogenic changes such as urbanization, construction of dams, etc.

- Although the sites analyzed here are spread widely throughout the U.S., gauge placement by the USGS is not a random process. Gauges are generally placed on larger, perennial streams and rivers, and changes seen in these larger systems may differ from those seen in smaller streams and rivers.

Data Sources

Data for this indicator came from the U.S. Geological Survey gauging station network, http://waterdata.usgs.gov/nwis. Analysis was conducted for the Heinz Center by David Raff and N. LeRoy Poff, Colorado State University (Raff and Poff, 2001; Raff, Howard, and Poff, 2001).

References

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Raff, D. 2001. Addendum to Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the *State of the Nation's Ecosystems Project* for The H. John Heinz III Center. Colorado State University.

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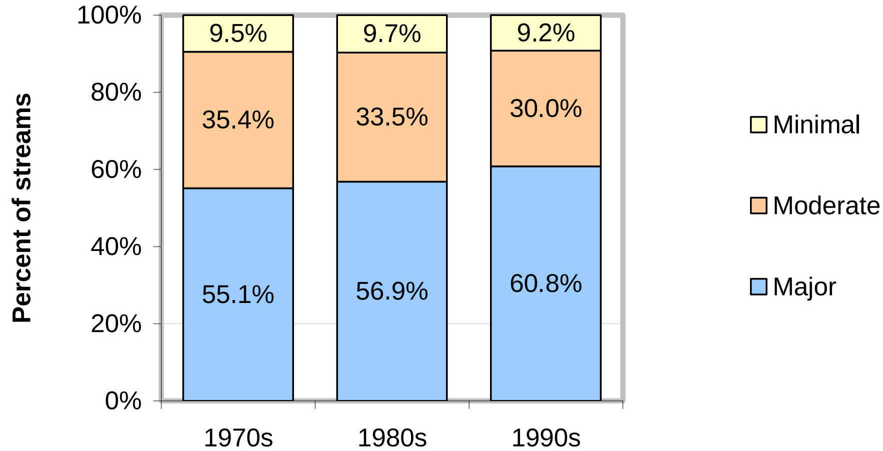
Graphics

Figure 029-1. Alteration of key flow characteristics (compared with 1930-1949)



Major: more than 75% increase or decrease in flow, or more than a 60-day change in timing of low or high flow.
Moderate: between 25% and 75% increase or decrease in flow, or a 30- to 60-day change in timing of low or high flow.
Minimal/stable: less than 25% increase or decrease in flow, or less than 30-day change in timing of low or high flow.

Figure 029-2. Major changes in high and low flow (compared with 1930-1949)

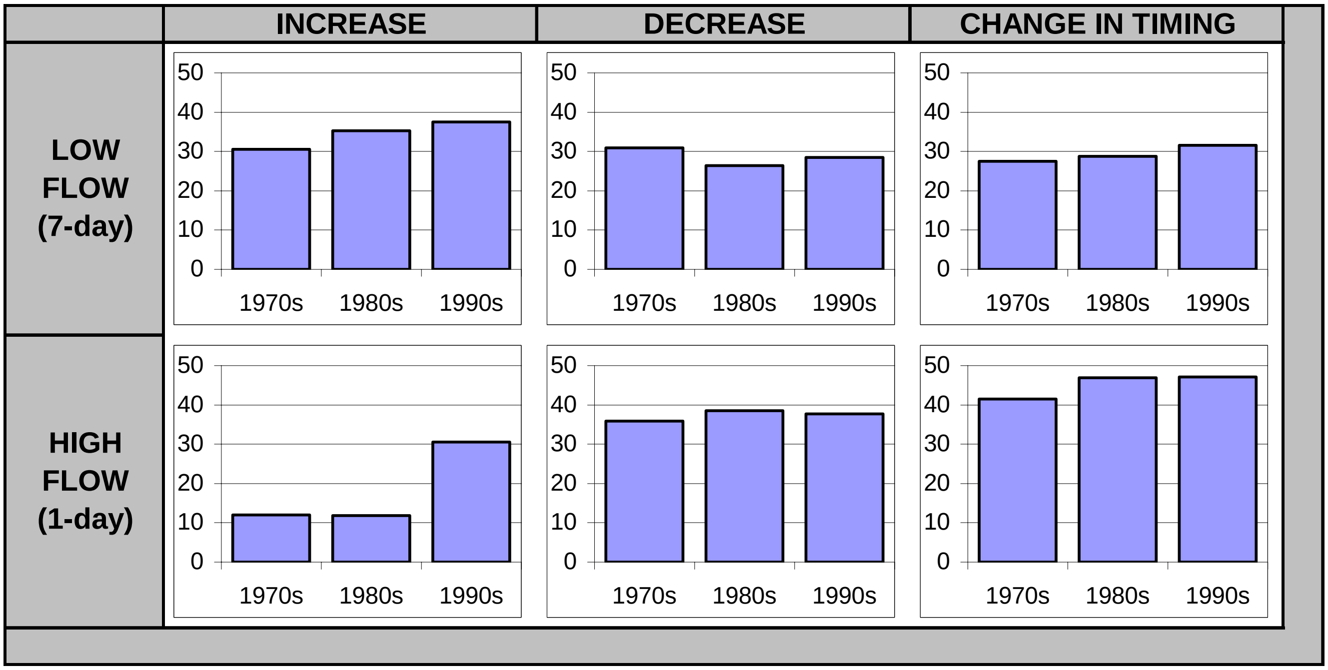


Figure 029-3. Percentage of grassland/shrubland streams experiencing periods of no flow

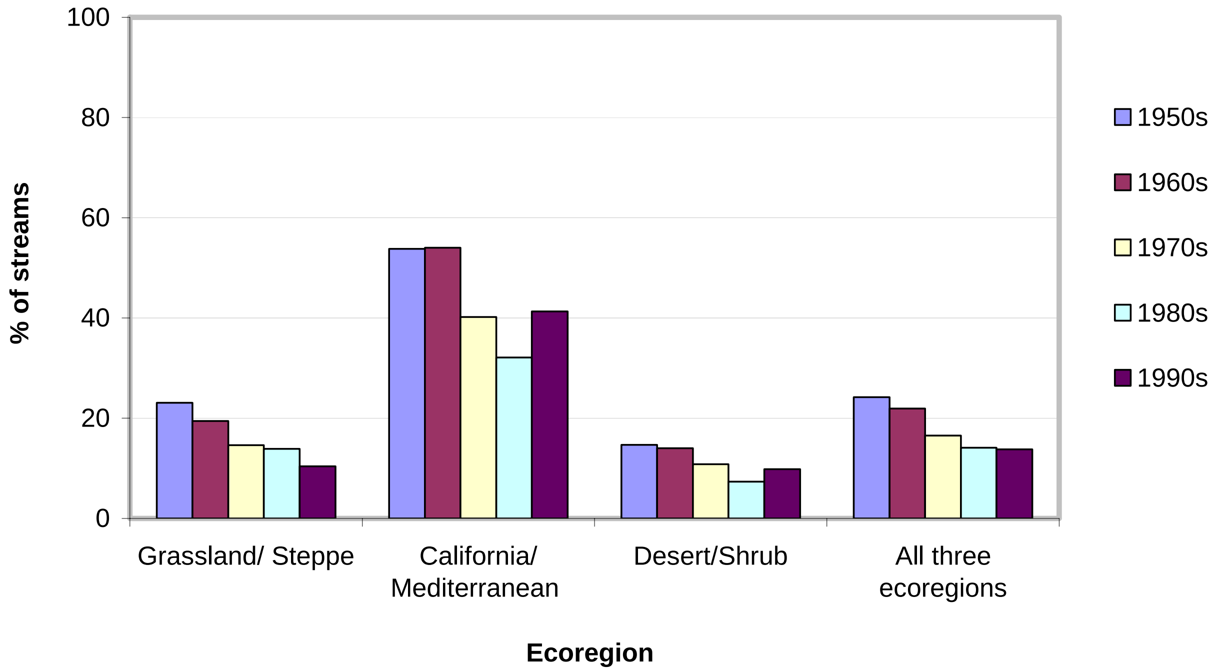
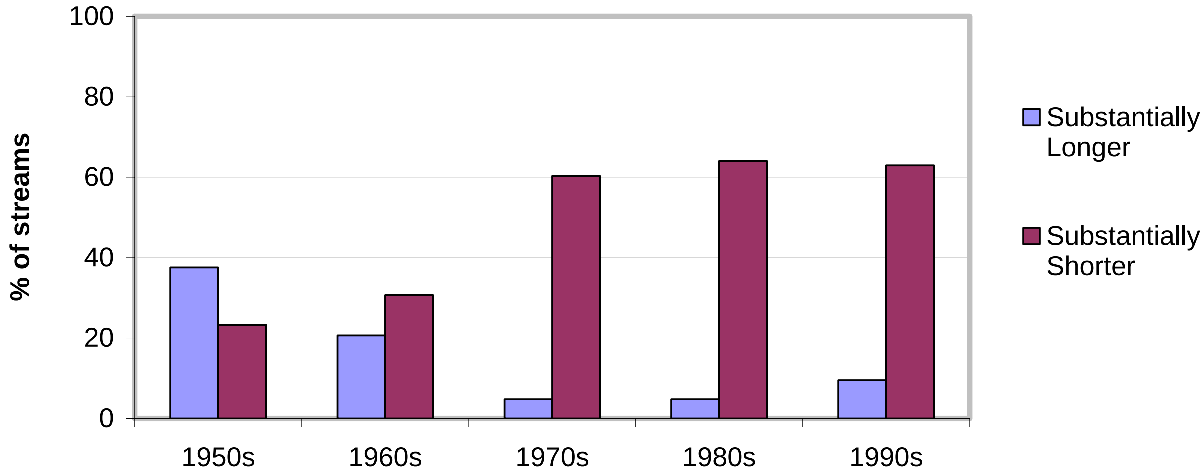


Figure 029-4. Duration of no-flow periods in intermittent streams* (compared to 50-year average, 1950-1999)



*For this analysis, an "intermittent" stream is any stream having at least one day of no flow between 1950 and 1999. A total of 143 grassland/shrubland streams met this criterion. Percentages reported in this chart are out of these 143 "intermittent" streams, not out of the full set of 408 grassland/shrubland streams.

A no-flow period is considered "substantially longer" if it is at least twice as long as the 50-year average for a given stream, and "substantially shorter" if it is 50% or less of the 50-year average. A decade without any no-flow days qualifies as "substantially shorter."

R.O.E. Indicator QA/QC

Data Set Name: CHANGING STREAMFLOWS
Indicator Number: 029 (89605)
Data Set Source: U.S. Geologic Survey
Data Collection Date: regular: 1949-1999
Data Collection Frequency: daily
Data Set Description: Combine: Changing Streamflows 029, Number/duration of dry stream flow periods in grasslands/shrublands 030, and Streamflow extremes in forest watersheds 343
Primary ROE Question: What are the trends in the critical physical and chemical attributes of the Nation's ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Yes. This indicator, which combines two Heinz Center (2002) indicators -- changing stream flows ("magnitude and timing") and dry periods in grassland/shrubland streams -- is derived from stream gauge measurements conducted by the U.S. Geological Survey (USGS) in the lower 48 states. USGS stream gauges at hundreds of locations collect raw data on either water depth or discharge volume (flow volume per second). If the equipment is not present to measure discharge directly (using a current meter), then depth is transformed into volumetric discharge using analytical methods described in T1Q3. USGS has been collecting stream gauge data since the late 1800s. Documentation of standard USGS field sampling procedures can be found online at http://water.usgs.gov/pubs/twri/.

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

Yes. USGS's network of stream gauging stations is designed to provide a comprehensive inventory of streamflow throughout the lower 48 states. USGS currently collects data from over 7,000 continuous monitoring stations (http://water.usgs.gov/wid/html/SG.html). Gauges are not placed randomly but are sited so as to capture information from relatively large, perennial streams and rivers (Heinz Center, 2002). Measurements are taken multiple times per day. For its "magnitude and timing" indicator, the Heinz Center used a subset of 867 stream gauging sites, chosen because each site met two basic criteria for data availability: (1) daily data for each year from 1970 to1999; and (2) daily data from 1930 to 1949, to serve as a baseline for comparison. (http://www.heinzctr.org/ecosystems/fr_water_technotes/fr_water_chg_strm_flows.shtml). [Note: The baseline may actually be any 20-year period within 4 years of the target period (1930-1949). This source of uncertainty is discussed in T4Q3.] The resulting 867-site sample is distributed across the entire 48 conterminous states, but with a higher density in the Northeast and Mid-Atlantic States, the Rocky Mountains, and the Pacific Northwest (Raff, D., and N. Poff 2001. Final Report on Hydrologic Alteration of Rivers and Streams in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University.) For its "dry periods" indicator, The Heinz Center selected two subsets of USGS measuring sites for analysis, one for each graphic. For its comparison of "Streams that have Zero-Flow Periods," the Heinz Center looked at all USGS measuring sites that had a complete 50-year record (October 1949 to September 1999) and were located within 4-digit Hydrologic Unit Code (HUC4) watersheds containing 50 percent or greater grass/shrub cover, corresponding with National Land Cover Dataset (NLCD) classes 31, 51, and 71 (http://landcover.usgs.gov/classes.asp). A total of

408 stream gauges met the criteria for "Streams that have Zero-Flow Periods." In their analysis of "Duration of Zero-Flow Periods," the Heinz Center included only those grassland/shrubland streams that had at least one day of zero flow during the 50-year period of interest -- a total of 143 data points out of the original 408. The Heinz Center does not discuss the spatial distribution of selected sites. However, the original analysis of the data includes a discussion of how data points are distributed among different "ecoregions" (Raff, D., S. Howard, and N. Poff 2001. Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University.; Raff, D. 2001. Addendum to Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University.) For a definition of ecoregions, see http://www.fs.fed.us/colorimagemap/ecoreg1_divisions.html.

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

The conceptual model used in transforming raw streamflow data into indicator data consists of two basic steps. The first step is conducted by USGS and involves the conversion of depth measurements to discharge data, reported in units of volume of water per second (daily averages). USGS describes conversion techniques at http://water.usgs.gov/pubs/twri/ (specific reference: Book 3, Chapter A10). This step is only necessary for those measuring sites that lack equipment to directly measure discharge (e.g., a current meter). Site-specific particulars on location and method of discharge measurement are available from USGS's site inventory (http://waterdata.usgs.gov/nwis/si). The second step is the analysis conducted by the Heinz Center in compiling its indicators. These steps are outlined in the Heinz report and in the underlying reports by Raff and Poff (2001) and Raff, Howard, and Poff (2001). Data for "magnitude and timing" are evaluated using Indicators of Hydrologic Alteration (IHA) software produced by the Nature Conservancy together with Smythe Scientific Software. Using this software, each decadal streamflow value is classified into one of three categories, based on the degree by which it differs from the 20-year baseline for the stream in question. Data are also categorized by the degree to which timing of peak streamflow has changed in relation to the baseline average. The IHA software is available from http://www.freshwaters.org/tools; this website also lists several peer-reviewed papers that support the IHA methodology. The rubric for final stream classification (three categories, based on the degree of deviation from the baseline) is located at http://www.heinzctr.org/ecosystems/fr_water_technotes/fr_water_chg_strm_flows.shtml. For the "dry periods" indicator, daily flow data from each stream were analyzed to determine: (1) whether the stream has experienced at least one zero-flow day over the course of the year; and (2) the duration of the zero-flow period (in days). For the latter quantity, each stream is compared with its 50-year average in order to classify a given year's dry period as either substantially longer than average (100 percent or greater increase), substantially shorter (50 percent or greater decrease), or neither. In both cases, annual data are averaged over the course of a decade. In addition, in compiling the zero-flow data, data points are sorted by land cover type and "ecoregion." The former designation comes from the National Land Cover Dataset (NLCD) and is used to select only sites with greater than 50 percent grass/shrub cover. The NLCD combines information from Landsat imagery and various government agencies and is documented at http://landcover.usgs.gov. The Bailey "ecoregion" designation used to break data down by ecosystem type is documented by: Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd ed. rev. and expanded (1st ed. 1980). Misc. Publ. No. 1391 (rev). Washington, DC: USDA Forest Service.

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

This indicator is conceptually appropriate for assessing the physical health of the nation's ecosystems. It is also well designed to report on broad trends in streamflow patterns, as each of the component indicators groups data by decade, and each includes a baseline for comparison. For "changing streamflows," the 867-site sample is distributed across the entire 48 conterminous states, but with a higher density in the Northeast and Mid-Atlantic States, the Rocky Mountains, and the Pacific Northwest (Raff, D., and N. Poff 2001, Final Report on Hydrologic Alteration of Rivers and Streams in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University). It is not clear whether this data set captures a significant percentage of the nation's total streamflow. USGS stream gauges are not placed at random; in general, they are sited on relatively large, perennial streams (Heinz Center, 2002). USGS does document the locations of its full inventory of gauging sites (http://nwis.waterdata.usgs.gov/nwis/si). The data set for "dry periods" is thorough in temporal terms: 50 years of daily average measurements, October 1949 to September 1999. Spatially, this component of the indicator includes 408 data points for one graphic ("Streams That Have Zero-Flow Periods") and 143 for the other ("Duration of Zero-Flow Periods"). While these numbers may appear small, they do represent the full extent of USGS data available to characterize grassland/shrubland streams and grassland/shrubland streams with a history of zero-flow periods, respectively. Sample design lacks some transparency, as neither the Heinz Center nor the underlying analysis discusses whether the geographic distribution of data points is sufficient to characterize broad, national-scale trends for grassland/shrubland streams (Raff, D., S. Howard, and N. Poff 2001. Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University). However, the paper by Raff, Howard, and Poff (2001) notes that data points are well distributed among several different ecoregions.

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

Sampling for "magnitude and timing" is not designed to give any special preference to streams that happen to contain sensitive populations or ecosystems, as this indicator is a composite of 867 streams that were chosen for data availability, not sensitivity characteristics. Sampling for "dry periods" is specifically designed to represent sensitive populations and ecosystems. Every stream in this indicator data set was chosen because of the type of ecosystem it supports (grassland/shrubland), while streams were included in the "Duration of Zero-Flow" graphic only if they had at least one day of zero flow during the 50-year sampling period. More than just changes in flow, the actual drying up of streams places great stress on any population that lives in the water. Thus every stream in this sample has populations and ecosystems that are sensitive to this stressor. In addition, changes in the duration of zero-flow periods can affect populations that have adapted their life cycles to specific drying-and-wetting regimes, and remain very sensitive to alterations in those regimes (Heinz Center, 2002).

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

Neither of the components of this stream flow indicator has an established reference point that unambiguously reflects the state of the environment. Both indicator components make use of a baseline average, but only to facilitate comparison. For "dry periods," the baseline for each stream is the mean number of annual zero-flow days, calculated over the 50-year sampling period. For "magnitude and timing," the baseline for each stream is 20 years of continuous measurements taking place primarily during the 1930s and 1940s. In the latter case, the baseline happens to be a period of historically low rainfall across much of the United States, including the period known as the "Dust Bowl" (Heinz Center, 2002). For both indicator components, the baseline period occurred after many significant human modifications had already been made to streams across the nation (e.g., dams and irrigation systems) (Heinz Center, 2002). Thus, neither baseline can be considered representative of an unmodified "natural state" of stream flow patterns.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Sampling and analytical procedures are well documented. Sample collection methodology is documented in USGS procedural manuals: depth (stage) gauging (http://water.usgs.gov/pubs/twri/twri3-A6/ and http://water.usgs.gov/pubs/twri/twri3a7/); conversion of depth to discharge (http://water.usgs.gov/pubs/twri/twri3-a1/ and http://water.usgs.gov/pubs/twri/twri3-a10/); direct measurement of discharge (http://water.usgs.gov/pubs/twri/twri3a8/). Analysis of "changing stream flow" data is described briefly by the Heinz Center, at http://www.heinzctr.org/ecosystems/fr_water_technotes/fr_water_chg_strm_flows.shtml, and in greater depth within the references cited by the organization that developed the software used for this analysis (http://www.freshwaters.org/tools). For the "dry periods" data, a basic description of analytical procedures is given in the Heinz report (http://www.heinzctr.org/ecosystems/grass_technotes/grass_dry_prds_strms.shtml). The "ecoregions" categorization methodology is discussed in: Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd ed. rev. and expanded (1st ed. 1980). Misc. Publ. No. 1391 (rev). Washington, DC: USDA Forest Service. Analysis of both indicator components was conducted by David Raff, Department of Civil Engineering, Colorado State University, and N. LeRoy Poff, Department of Biology, Colorado State University. Their reports detail the criteria for data selection and the steps of their analysis. Raff, D., and N. Poff 2001, Final Report on Hydrologic Alteration of Rivers and Streams in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University. Raff, D., S. Howard, and N. Poff 2001. Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University. Raff, D. 2001. Addendum to Report on Hydrologic Alteration of Rivers and Streams in Predominantly Grassland and Shrubland Ecosystems in support of the State of the Nation's Ecosystems Project for The H. John Heinz III Center. Colorado State University.

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

Discharge data for all of USGS's stream gauge locations can be obtained online at http://nwis.waterdata.usgs.gov/usa/nwis/discharge. Some of these locations have been monitored since the late 19th century, but for others, data are only available for recent decades. At some locations, USGS does not measure discharge directly. Here, USGS calculates daily discharge using measurements of stream depth, which are also available online (http://nwis.waterdata.usgs.gov/usa/nwis/measurements). USGS publishes a full inventory of its monitoring sites, including exact location and the types of measuring equipment in use (http://waterdata.usgs.gov/nwis/si). The land cover data used to choose sites for "dry period" analysis can be obtained from an NLCD (National Land Cover Dataset) website administered by

USGS's Earth Resources Observations Systems (EROS): http://landcover.usgs.gov. "Ecoregions" are defined and delineated at http://www.fs.fed.us/colorimage map/ecoreg1_divisions.html. The Heinz Center has not published the exact list of stream gauging sites included in either of its streamflow indicators, but the underlying analyses by Raff and Poff (see T3Q1 for citations) offer thorough descriptions of the criteria used in querying USGS data for inclusion. Complete analytical output can also be found in the Raff and Poff reports cited in T3Q1. The Heinz Center has published the numerical data from the graphs in the 2002 Heinz Report:
1.http://www.heinzctr.org/ecosystems/fr_water/datasets/freshwater_changing_stream_flow_characteristics.shtml;
2.http://www.heinzctr.org/ecosystems/fr_water/datasets/freshwater_changing_stream_low_flow.shtml;
3.http://www.heinzctr.org/ecosystems/fr_water/datasets/freshwater_changing_stream_high_flow.shtml;
4. http://www.heinzctr.org/ecosystems/grass/datasets/grass-shrub_perennial_zero_flow_periods.shtml;
5.http://www.heinzctr.org/ecosystems/grass/datasets/grass-shrub_perennial_duration_zero_flow_periods.shtml

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

In general terms, the study design is sufficiently well documented to allow both components of this indicator to be reproduced. Using USGS discharge data as a starting point, the methodology involves selecting data points that meet certain criteria (see T1Q3), calculating average values and percent changes, and then classifying data by either the degree of change or the physical "ecoregion" represented. The IHA software program used by Heinz may be obtained free online, making re-analysis even easier. Because the Heinz Center has not provided specific information about which USGS gauging stations were included in either of their analyses, it may be difficult to reproduce the Heinz Center's figures exactly. However, it may be possible to reproduce the list of data points included in each analysis using query criteria from the Raff and Poff reports (see T3Q1) and information from the NLCD.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

The USGS procedural manuals cited in T3Q1 provide detailed technical information about collection equipment. These manuals do not specifically discuss QA/QC, but another USGS publication provides very thorough coverage of both accuracy and QA/QC for stream stage and discharge equipment (Rantz et al., "Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge," http://water.usgs.gov/pubs/wsp/wsp2175/pdf/WSP2175_vol1a.pdf). QA/QC procedures for the analytical stages used in creating this indicator are not documented in the Heinz Report or the Raff and Poff reports (citations in T3Q1).

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

This indicator does not require any projection of data beyond the temporal bounds of the measuring periods, because all of the streams chosen for analysis have daily flow data for the entire period of measurement. The main sources of temporal generalization are the simple process of averaging daily figures to get yearly or decadal mean values (for "magnitude and timing") and the similarly simple process of summing the number of zero-flow days to get annual and consecutive-day values (for "dry periods"). This generalization reduces the influence of outlier values by smoothing the data set over longer time periods, and provides a means for easy graphical analysis. No statistical procedures have been used either to portray data beyond the spatial extent of sampling or to generalize the data spatially. The only possible example of spatial generalization related to this indicator is if the observer interprets the data to be quantitatively representative of either the nation as a whole or the individual "ecoregions" by which the data may be divided.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

The Heinz Report does not provide any quantification of uncertainties associated with this indicator, either in the original data set or in the analytical output. For raw discharge measurements, USGS has published a general online reference devoted to the calculation of error (Sauer and Meyer 1992, "Determination of error in individual discharge measurements," http://pubs.er.usgs.gov/pubs/ofr/ofr92144). The Raff and Poff report for "magnitude and timing" (2001) includes a chart of 95 percent confidence intervals for each of the final outputs. The Raff and Poff report for "dry periods" does not include a similar analysis. An uncertainty measurement has been published for the National Land Cover Dataset (NLCD), which is used to screen stream gauging points for inclusion in the "dry periods" analysis. According to the Heinz Center, the NLCD has 80 percent or higher accuracy for the eastern United States, while the western United States is still under review. A detailed discussion of error in the NLCD can be found at http://landcover.usgs.gov/accuracy. No similar information is immediately available in reference to the delineation of "ecoregions," but such information may be included in the original document that developed this approach: Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd ed. rev. and expanded (1st ed. 1980). Misc. Publ. No. 1391 (rev). Washington, DC: USDA Forest Service.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

As noted in T4Q2, uncertainty is explicitly quantified for "magnitude and timing." Confidence intervals are not so large that they drastically reduce the utility of the indicator, but they do suggest that this indicator should be taken more as evidence of general trends than as an exact set of numbers. The Heinz Center and the underlying data report do not quantify uncertainty for "dry periods," although this uncertainty might be expected to be larger than error for "magnitude and timing," since the data set is smaller. Variability is not quantified, but it is expected that streamflow will vary on a daily or even hourly basis. USGS handles this variability by making measurements several times a day and then reporting a daily average. However, additional uncertainty in the Heinz Center's "magnitude and timing" indicator may limit the utility of comparing modern data to baseline values. The Heinz Center compares streamflow with a baseline that is not consistent across all gauging stations. While all stations have a 20-year baseline, this 20-consecutive-year period is not specifically defined as 1930-1949. Instead, periods used may deviate from this standard period by up to 4 years, depending on data availability.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

(1) This indicator measures environmental condition, not the causes of that condition. The 1980s appear to be marked by higher streamflows and fewer streams with zero flow, but it is not known whether this is a result of high precipitation, changes in precipitation patterns, changes in plant communities, changes in water management policies (e.g., diversion for irrigation), development, or a combination of factors. (2) The "magnitude and timing" indicator compares streamflows in decades 1970-1999 to a baseline period, 1930-1949. In some parts of the country, this period saw rainfall well below longer-term averages (Heinz Center, 2002). In addition, many dams, water works, and other forms of human interference with streamflow were introduced during or prior to this baseline period. As such, baseline values do not necessarily represent a "normal" or "natural" state. (3) Gauge placement is not a random process. USGS gauges are generally placed on larger, perennial streams and rivers (Heinz Center, 2002). Thus, small or intermittent streams may be underrepresented or undercounted. Changes observed in the larger streams may differ from those seen in smaller rivers or streams. (4) Some bodies of water have gauges operated by other entities like the U.S. Army Corps of Engineers (USACE), but only data from USGS gauges were used in calculating this indicator (Heinz Center, 2002). The Heinz Center does not discuss the extent to which USACE gauges may represent waterways that are already measured by USGS gauges.